(12) UK Patent Application (19) GB (11) 2 262 803 (13) A

(43) Date of A publication 30.06.1993

(21) Application No 9127358.1

(22) Date of filing 24.12.1991

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(51) INT CL^5
G01B 11/16

(52) UK CL (Edition L)
G1A AA3 AA6 ABG AC8 AG1 AG11 AG17 AG4 AG6 AG7 AMQ AR7 AT14 AT21 AT5
H4D DLF D72X D749 D751 D759 D776 D782 D783

(56) Documents cited
GB 2250593 A GB 2214636 A GB 2209212 A
GB 2202046 A GB 2190262 A GB 2126820 A

(58) Field of search
UK CL (Edition K) G1A ABG ACE AMQ, H4B BK12 BK12M BK12S BK20 BK20S BK20S1 BK20S2 BK20T BK20T1 BK20T2, H4D DLF
INT CL^5 G01B, G01L, G01M, G01N, G01P, G08B H04B

(54) **An optical fibre sensor array**

(57) A linear strain sensor is described, consisting of a cabled or jacketed optical fibre. Light travelling through the fibre, is phase modulated by the strain, which is detected using reflectometric interferometry. The sensor is suitable for intruder detection, structural monitoring and monitoring of vehicles on the highways.

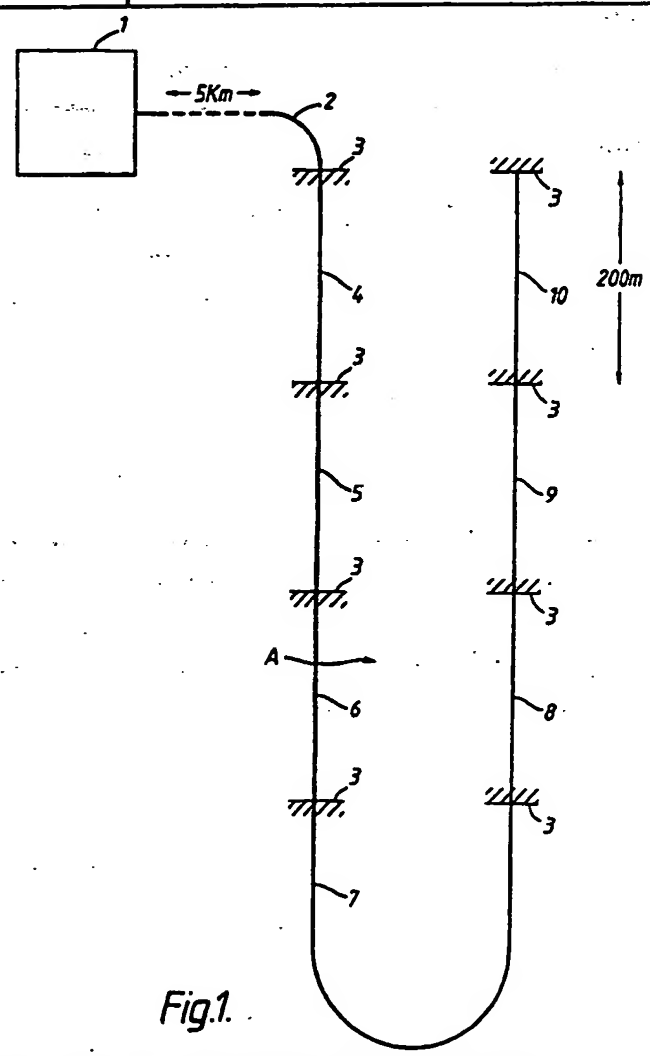

Fig.1.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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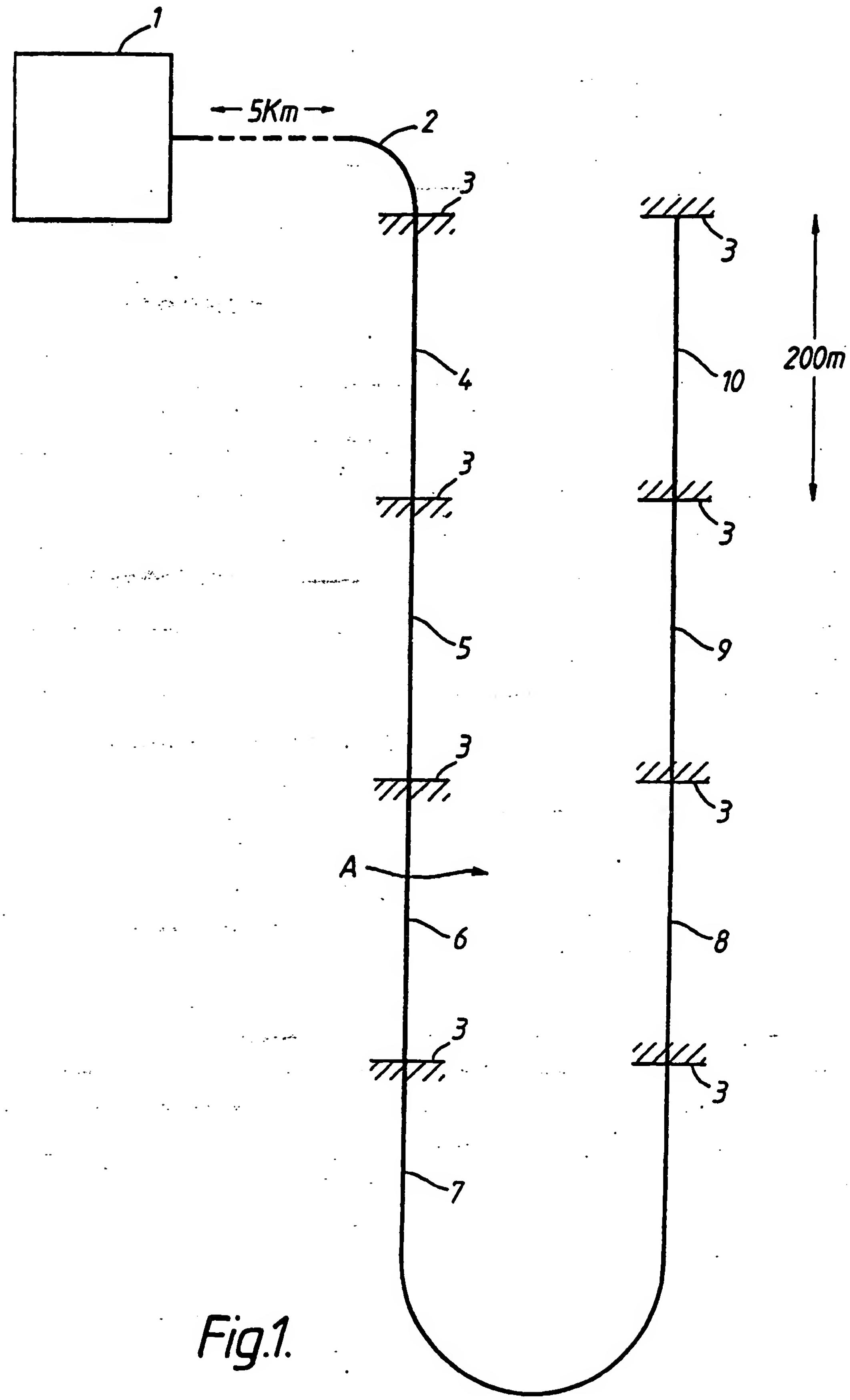

Fig.1.

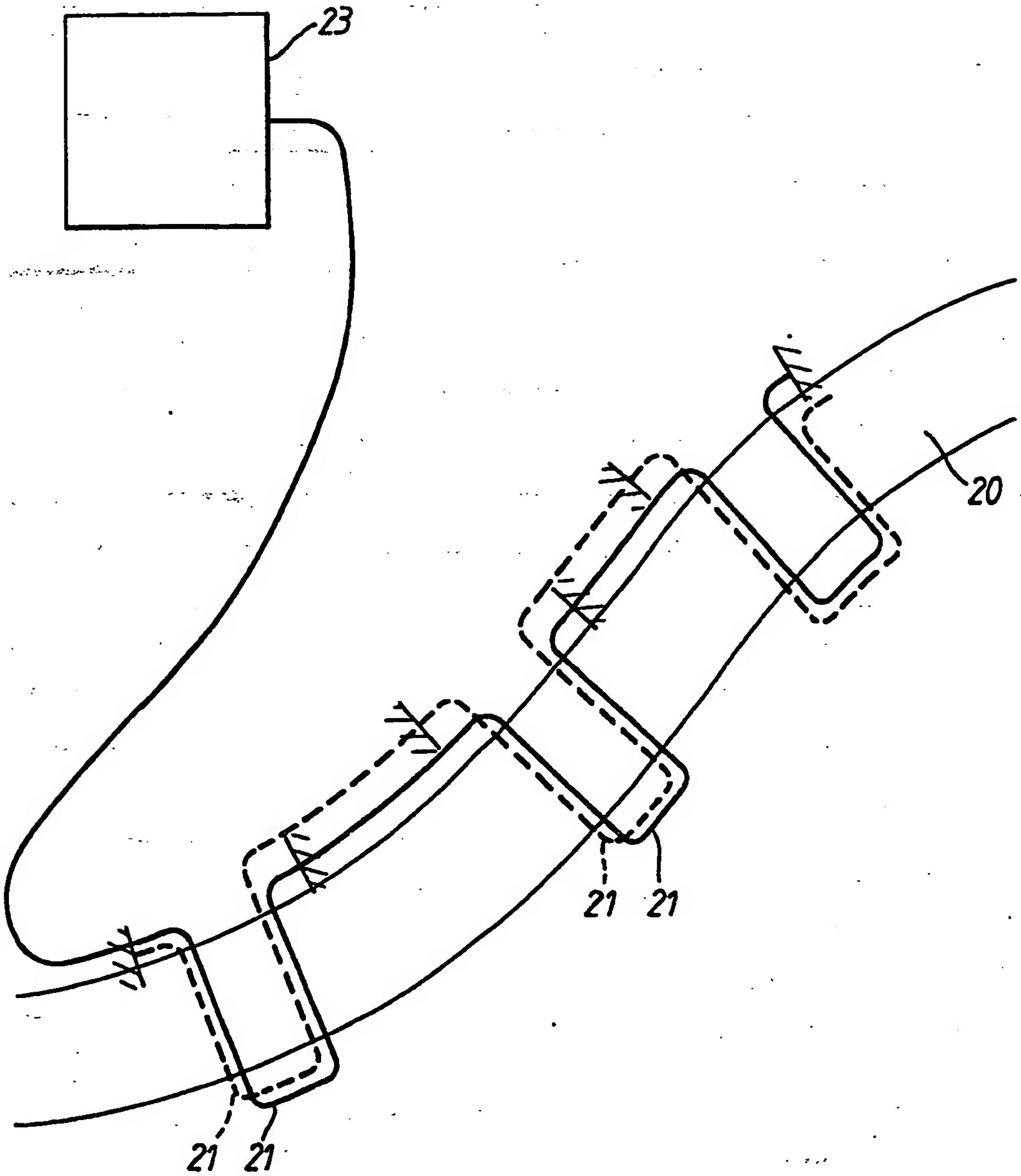

Fig.2.

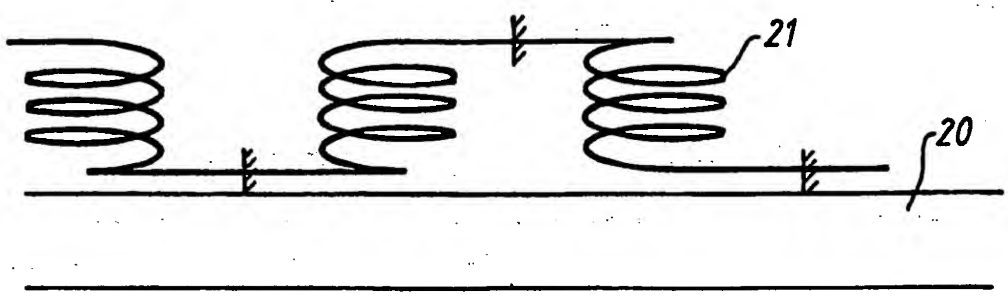

Fig. 3.

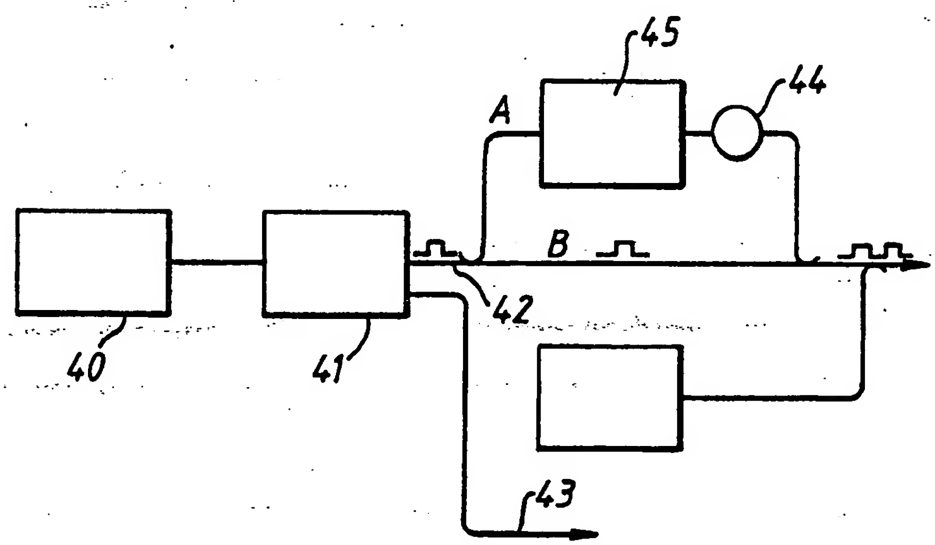

Fig. 4.

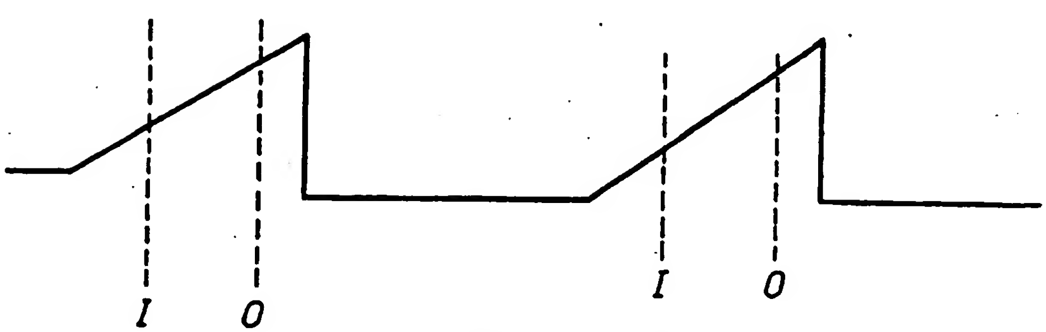

Fig. 4 A.

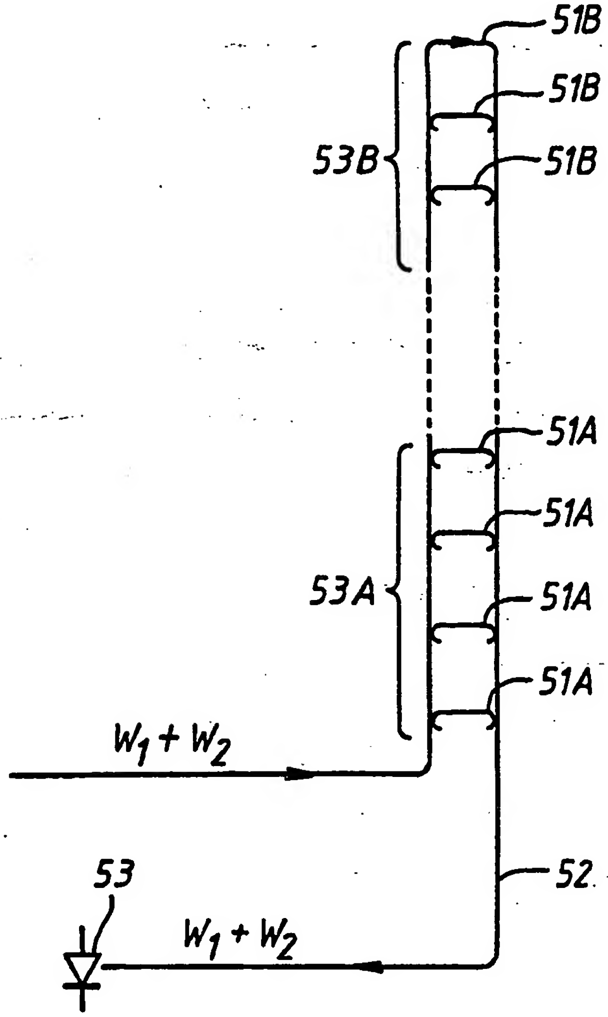

Fig. 5.

An Optical Fibre Sensor Array

This invention relates to an optical fibre sensor array, and in particular to such an array for detecting strain.

Optical fibres have been employed in many types of detection systems. One particular application in which they have previously been used is for the detection of acoustic pressure waves in water. In order to detect such pressure waves and to obtain information about the wave, for example directivity, it is necessary to employ a plurality of optical fibre sensors usually in a linear array. As such arrays are often towed behind a marine vessel optical sensors arrays for such applications have been developed so that the sensor array comprises of only optical fibre material, all contact with the array being by the propagation of light along the fibre, enabling all the electronics for producing the light signals and processing the received signals to be mounted remote from the array for example on board the marine vessel towing the array.

One such optical sensing system as described above is disclosed in our UK patent application Publication No.

2136113. This discloses a sensor array comprising a single optical fibre 6, having along its length discontinuities which define respective sensors comprising of the lengths of fibre between each adjacent pair of discontinuities. A similar arrangement is shown in our co-pending application number 9124589.4 wherein a plurality of light sources are used to send a plurality of light signals down a single fibre, with respective sets of optical sensing elements being associated with different light sources enabling a greater number of optical sensors to be deployed.

The present invention arose from the realisation that apparatus similar to that disclosed in the above referred to applications could be advantageously applied for detecting strain on the surface of, or within, a structure.

According to the present invention there is provided an optical fibre sensor array including an optical fibre, a light source for transmitting light signals into the fibre, and detector means, the fibre comprising a plurality of sensor elements, each being a length of the optical fibre positioned on, or under, a surface on which strain is to be detected, the lengths of optical fibre being defined by redirecting means for redirecting light signals propagated along the sensor array to the detecting means.

By providing an optical fibre sensor in accordance with the invention it is possible to sense strain at multiple locations, with the only connection required being by a single optical fibre. This provides that the electronic processing data and light source can be far removed from the sensed area and does not require electrical signals to be transmitted to the sensed area, which may be advantageous in areas of high fire risk.

Preferably the redirecting means comprises partial reflectors for reflecting light signals back along the single optical fibre to the detector arrangement such that only one fibre need be provided between the light source/detector arrangement and the sensor elements. These partial reflectors may be reflective optical couplers. Alternatively the redirecting means may comprise optical coupling means for redirecting light to an optical fibre other than said single optical fibre for transmission to the optical detector arrangement.

Advantageously a reference cable is positioned in close proximity to the sensor array to permit common-mode noise to be cancelled, for example laser noise or geological noise, which would be common-mode rejected, leading to a

lowering of the noise floor and hence an increase in sensitivity.

In certain applications it is desirable that the detection means comprises means for analysing the return signal and means for comparing it with stored data in order to classify the detection and thereby identify what has been detected.

Preferably the light source comprises a laser source and an optical switch for directing light from the laser source along two paths one of which has an optical delay therein and one of which has an optical phase shifter therein, such that in use the light source transmits to the fibre two time displaced pulses at different frequencies, such an arrangement permitting a semiconductor laser to be used as the light source.

An array in accordance with the invention can advantageously be employed for monitoring vehicles on a highway, for detecting an intruder, or for detecting displacement of machinery. Several embodiments of the invention will now be described by way of example only with reference to the accompanying drawings of which:

Figure 1 is a schematic illustration of an intruder detection system in accordance with the invention;

Figure 2 is a schematic diagram of a vehicle monitoring system in accordance with the invention;

Figure 3 is a schematic diagram of an alternative arrangement of the apparatus of Figure 2;

Figure 4 schematically illustrates a light source arrangement;

Figure 4a schematically illustrates the output of the light source of Figure 4; and

Figure 5 depicts one possible sensor arrangement in accordance with the invention.

The devices depicted in the Figures use the modulation of rays of light within the fibre caused by straining of the fibre.

Referring now to Figure 1 there is illustrated an intruder detection system comprising a control point 1 housing a light source and detector arrangement, a fibre

optic cable 2 surrounded by a Kevlar* strain member and overlaid with a protective plastic jacket. Attached to the optical fibre 2 are optical couplers 3 forming reflective discontinuities which redirect part of the light signal propagating along the fibre from the light source in the control point 1 back to the detector in the control point. Each section of fibre 4,5,6,7,8,9 and 10 between each pair of adjacent optical couplers 3 forms a sensor element. These sensor elements are placed just below ground level so that they are strained by an intruder placing his weight on the ground in the region of these elements.

An intruder crossing the double line of buried sensors at 'A' will be detected by sensor 6, followed by sensor 8, providing speed and direction information. Sensors 6 and 8 are arranged so that their outputs are set to cancel each other in the electronic processing within the detector. In this case, any common mode ambient or instrumental variations due, for example, to laser noise or geological noise, will be common mode rejected, leading to a lowering of the noise floor and hence an increase in sensitivity.

* A TRADE MARK

In the example shown in Figure 1, a total invigilated length of 600 metres is shown, situated at a distance of 5Km form the control point 1. This can be greater both in detection length and in downlink length, with intruder localisation to within 100-200 metres.

Signal demodulation is carried out in control point 1 by methods currently used in optical hydrophone arrangements. Typical signatures, (footsteps for example), occupy a restricted frequency range (below 500Hz) and have a characteristic spectrum. Knowledge of this spectrum provides a method of classification, following detection (using for example a simple level detector). Matched filtering, and correlation techniques are used, with stored replica target characteristics.

Referring to Figure 2, another application is illustrated for monitoring vehicles on a highway 20. Fibres 21, similar to these described with reference to Figure 1, are laid under the highway 20 and monitor the axle weight and speed of vehicles crossing the cable, the amplitude of the signal being related to the force (and hence vehicle weight) impressed on the cable. The signals are generated at control point 23 which also processes the returned signals. A second set of reference cables could be placed

close to the first set, to cancel the effects of common-mode noise from sources other than traffic.

An alternative approach which reduces installation costs on existing carrageways is illustrated in Figure 3. Here the cables 31 are located at the side of the road (or in the central reservation). This is more difficult to calibrate and is less sensitive than the Figure 2 arrangement, but appropriate configuration of the cable run (either as, a column or zigzag) either in the surface of the roadside, or off the road, can allow satisfactory operation in certain applications.

A further application of the strain sensor (not illustrated) is for monitoring vibration of machinery, structures, aircraft etc. In these cases the cable is incorporated within the structure or attached to the outside. Vibration above 1-5Hz can be monitored, and any change in characteristics of the spectrum or amplitude detected. The advantage of this technique is the economical deployment of many sensors, so in this case, it would be of most advantage in very large structures such as ships, oil rigs etc.

Figure 4 depicts apparatus suitable as a light source

for the systems described with reference to Figures 1 to 4. This comprises a semiconductor laser 40 which generates light that passes through a switch 41 producing a pulse on fibre 41. The switch can be connected to produce pulses on similar lines 43 (only one of which is shown) leading to similar arrays. The pulse traveling along fibre 42 travels on two paths A and B. A fibre delay 44 in path A causes a pulse entering the system to leave as two separated pulses, as required for the multiplexing scheme. Also in path A there is an optical phase shifter 45 capable of providing a linear phase ramp on one of the pulses. This results in an effective optical frequency change on one of the pulses, as required. Timing of this scheme is shown in Figure 4a, in which a linear phase ramp is shown. Alternatively a phase sinusoid could be used, and switched only on the linear portion. The required phase ramp (or sinusoid) could be obtained in two ways, either by winding fibre on a piezoelectric "stretcher" mandrel, or by using an integrated optical phase shifter. The delay 44 can be a fibre coil.

Referring now to Figure 5, there is illustrated a variation on the apparatus previously described, wherein the optical couplers 51A and 51B are frequency dependant, 51A being transmissive to a first frequency W1, and 51B being transmissive to a second frequency W2. In this way sensor

elements 53A and 53B only modify W1 or W2 respectively enabling extended arrays of sensors to be provided, as for example in this embodiment signals of wavelength W2 will not be attenuated by couplers 51A. These couplers can be reflective, as previously described, or alternatively as disclosed in Figure 5, couple signals to a return fibre 52.

Claims

1. An optical fibre sensor array including an optical fibre, a light source for transmitting light signals into the fibre, and detector means, the fibre comprising a plurality of sensor elements, each consisting of a length of the optical fibre positioned on, or under, a surface on which strain is to be detected, the lengths of optical fibre being defined by redirecting means, the redirecting means redirecting light signals propagated along the sensor array to the detecting means.

2. A sensor array as claimed in any preceding claim wherein the redirecting means comprise partial reflectors for reflecting light signals back along the single optical fibre to the detector arrangement.

3. A sensor array as claimed in claim 2 wherein said reflectors comprise reflective optical couplers.

4. A sensor array as claimed in claim 1 wherein the redirecting means comprise optical coupling means for redirecting light signals to an optical fibre other than said optical fibre for transmission to the optical detector

arrangement.

5. A sensor array as claimed in any preceding claim wherein a reference cable is positioned in close proximity to the sensor array to permit common-mode noise to be cancelled.

6. A sensor array as claimed in any preceding claim wherein the detection means comprises means for analysing the returned signal and means for comparing it with stored data in order to classify the detection.

7. A sensor array as claimed in any preceding claim wherein the light source comprises a laser source, and an optical switch for directing light from the laser source along two paths one of which has an optical delay therein and one of which has an optical phase shifter therein, such that in use the light source transmits to the fibre two time displaced pulses at different frequencies.

8. A sensor array as claimed in any one of claims 1 to 7, in which the light source comprises a Bragg cell for combining and launching light signals of different wavelengths into the single optical fibre, the Bragg cell being arranged to be pulsed sequentially at different

predetermined frequencies in order to produce like deflections of incoming light signals at different wavelengths.

9. A sensor array as claimed in any preceding claim for monitoring vehicles on a highway.

10. A sensor array as claimed in any one of claims 1 to 8 claim for detecting an intruder.

11. A sensor array as claimed in any one of claims 1 to 8 for detecting displacement of machinery.

12. A sensor array as claimed in any preceding claim comprising means for generating a plurality of light sources of different frequencies, and a plurality of sets of redirecting means, wherein different set of redirecting means are associated with different light sources.

13. An optical fibre sensor array substantially as hereinbefore described with reference to any one of the accompanying drawings.

Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number
91[illegible]58.1

Relevant Technical fields

(i) UK Cl (Edition K) H4B: BK12;BK12M;BK12S;BK20;BK20S; BK20S1;BK20S2;BK20T;BK20T1;BK20T2; G1A: BG;CEX;MQX; H4D;DLF

(ii) Int CL (Edition 5) G01N, G01B, G01L, G01P, G08B, H04B, G01M

Search Examiner

A C STRAYTON

Databases (see over)

(i) UK Patent Office

(ii)

Date of Search

17 JUNE 1992

Documents considered relevant following a search in respect of claims ALL

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2250593 A - entire document	1-13
X	GB 2214636 A - entire document	1-13
X	GB 2209212 A - entire document	1-13
X	GB 2202046 A - entire document	1-13
X	GB 2190262 A - entire document	1-13
X	GB 2126820 A - entire document	1-13

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

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